AEI

Electrical Distribution

THE NEWS MAGAZINE OF THE CABLE DIVISION AND CONSTRUCTION (CABLES & LINES) DIVISION OF ASSOCIATED ELECTRICAL INDUSTRIES LTD

CONTENTS

	Page
News in brief	174
Blue Train Teamwork	
Japanese O.H.L. Balloon Lift	
Telephone Cable Manufacture	
Kincardine—£171 000 Cabling	
Cross-Channel Power Link. Jointing the Cables in mid-Channel	175
Progress in British Standards	179
Drake & Gorham—75 Years	179
New Five-way Connector Box	180
Lead Sheathing Booklets	180
Wiring History since 1870	180
Computer Tools for the Analysis of Power System Problems	181
New British Standards	188
West Country Supergrid Work	189
Expanding Horizons in Communications	190
E.I.B.A. Report	190
Back to Agecroft	191
Problem Circle	192

EDITORIAL

THE CROSS-CHANNEL power cables were first tested for short periods at reduced power level early in October, power being transferred in both directions between Britain and France.

Since then rigorous testing has continued. The 160MW power link should shortly be operating on a commercial scale.

The final operation on the underwater cables before testing took place was the jointing of the British and French cables in mid-Channel. In this issue is a stage-by-stage account of the work carried out by French jointers on board their cable ship *Ampère*.

. . . . . .

Computer-mindedness is evident in many industries today, and not least in the field of electricity transmission. Many engineers and students of electrical engineering at home and abroad have, as yet, little practical contact with the work involved in the use of network analysers and electronic computers to investigate power system problems. In the belief that an account of the subject will prove widely acceptable to our readers, we present on page 181 the first part of a two-part article on 'computer tools', specially angled to interest the power engineer.

AEI

Published by Associated Electrical Industries, Publicity Department, for the Cable Division and Construction (Cables and Lines) Division. Editorial Offices: Crown House, Aldwych, London, W.C.2, England. Telephone: Temple Bar 8040. Issued in alternate months.

OUR COVER PICTURE

A stretch of Supergrid which will eventually operate at 400kV has been erected in Somerset by AEI Construction Division. It links Hinkley Point nuclear power station with Taunton and completes a West of England scheme for the Central Electricity Generating Board.

News in brief...

Blue Train Teamwork

WHEN THE BLUE trains of Glasgow's Suburban Service (see ELECTRICAL DISTRIBUTION, Vol. 1, No. 3, November 1960) were reintroduced on 2 October by the Scottish Region of British Railways, public interest was so great that extra trains had to be run on the first day to carry all the passengers. Since then they have transported twice the number of passengers than the steam trains carried, and as far as the people of Glasgow are concerned there is no doubt about the success of the electric trains.

When the transformer failures occurred last year, it was obvious that the transformers had been subjected to extreme stresses. Although the cause of this was not known, AEI decided immediately in view of the unknown factor to rebuild all transformers to the utmost strength.

Christmas holidays went by the board for all those concerned during investigations and when the time came for actual rebuilding, efforts were even more intensified.

All resources of AEI were mobilized in Manchester and Rugby; in addition, British Railways placed Dukinfield at the Company's disposal. A crash rebuilding programme was arranged and given top priority in the AEI Transformer and Traction Departments at Manchester and Rugby with the result that by the middle of February the first rebuilt transformer was delivered to be mounted on the trains.

The first modified train was completed in mid-March and by the end of May fifty-seven trains had been modified and returned to Glasgow. Trial services to the end of September proved the trains trouble-free.

Unstinted round-the-clock working by AEI workers accomplished this programme. The feeling that remains amongst all in AEI who had to meet the Glasgow emergency is of the inspiring way in which every man, whether on the shop floor or on executive duties, reacted to the challenge.

Japanese O.H.L. Balloon Lift

JAPANESE OVERHEAD LINE engineers, precluded by conditions in the turbulent Naruto Straits from using conventional boat techniques or helicopter assistance to get conductors across, used balloons.

The 5 900ft span across the Straits was negotiated by reeving a 9mm pilot wire through blocks on the crossing tower on the Awaji shore. When the current through the Straits was at its slowest, a tug pulled the wire slowly across the Straits while workers on shore fastened 8–9ft diameter balloons to it at 65ft intervals. Each balloon had a lifting capacity of about 16½lb and the wire was lifted clear of the water as it travelled across the Straits. Seventy-seven balloons were found necessary.

Meanwhile, a 12mm wire, reeved through blocks on the Naruti shore crossing tower opposite, was carried by another tug to meet the first a short distance off-shore. When the two wires were spliced and released, the balloons lifted the cables above the Straits.

Consequent operations were to pull the 9mm pilot wire back, followed by the 12mm wire and to progressively increase the size of the pilot wire until all was ready to pull the 35·5mm 170kV crossing conductors across the Straits.

Telephone Cable Manufacture

ASSOCIATED ELECTRICAL INDUSTRIES LTD and Enfield Cables Ltd have now transferred all their business in paper-insulated and polythene-insulated telephone cables, and co-axial and other high-grade cables for telecommunications, to Telephone Cables Ltd, Chequers Lane, Dagenham, Essex.

Telephone Cables Ltd, formed in January this year and jointly owned by AEI and Enfield Cables, is now handling all home and export business in this field for both companies.

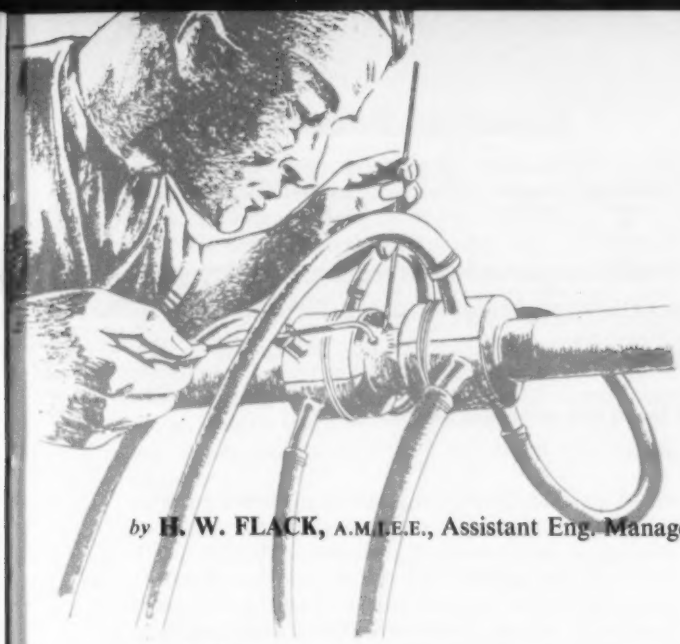
Telephone Cables Ltd has at Dagenham the most modern telephone cable production unit in the United Kingdom. It is the largest supplier of telephone cables to the British Post Office, for whom it also carries out extensive trunk cable installations. A large staff of experienced engineers can advise on cable requirements, assist in the design of cable networks, and carry out or supervise telephone cable installations anywhere in the world.

Kincardine—£171 000 Cabling

A FURTHER CONTRACT for work at Kincardine Generating Station has been awarded to Associated Electrical Industries Ltd.

The new contract, valued at £171 000, covers the supply and installation of cables and accessories, including cable supporting steelwork, for two 200MW generating sets at Kincardine B Power Station. The work will be carried out by AEI Construction (Cables and Lines) Division for the South of Scotland Electricity Board. Consulting engineers for the project are Messrs Kennedy and Donkin.

The cable will be manufactured by AEI Cable Division at its Gravesend and Woolwich factories and will include 11kV and lower voltage paper- and cambric-insulated types, 250V p.v.c. insulated cables, and p.v.c. insulated telephone cables.



JOINTING THE CABLES IN MID-CHANNEL

by **H. W. FLACK,** A.M.I.E.E., Assistant Eng. Manager—Super Tension Cables Dept., AEI Cable Division

Introduction

The final stage of the cabling operation of the cross-Channel project was the jointing of the French to the British cables at the mid-Channel position. It had been previously agreed by the Électricité de France and the Central Electricity Generating Board that these joints would be made by the French.

The four cables had been laid from the French and British shores and at the mid-Channel position the ends had been turned out at right angles to the line of the cable route. Prior to the actual jointing operation, surplus cable had been picked up by the French cable ship *Ampère* and moorings had been laid off the four quarters of the ship's jointing position.

Arrangements had been made for the joints to be made on the cable ship *Ampère* and she was attended by an older cable ship the *Émile Baudot* and a French naval tug. The voyage was to be the last for the *Émile Baudot* which returned to Le Havre after the operation to be laid up after forty-four years of service.

On the morning of 21 June 1961, with moorings laid and the weather set fair, the ships assembled at the mid-Channel position and by midday the *Ampère* was moored at Latitude 50° 48′ 34″ North and Longitude 1° 15′ 53″ East and the cable ends, each pair having previously been bound together, were picked up and hauled aboard.

The positioning of the cables on the deck for the making of the joints is shown schematically in figure 1.

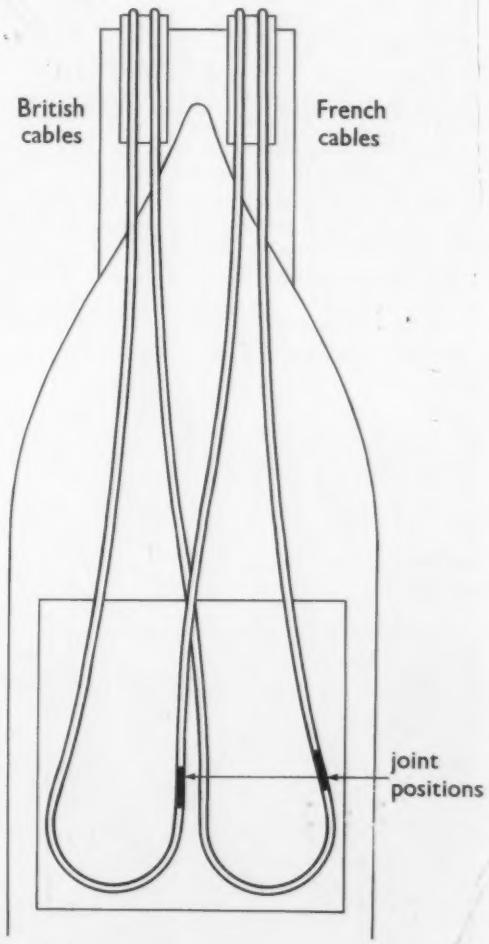


Fig. 1. Layout of cables for jointing on deck of cableship "Ampère".

Preparation of the cables

The cables were first supported on trestles and overlapped sufficiently to give appropriate lengths of armour wires to provide for the finished overlaid splice. It was arranged that the 'short' armour should be on the French cables and the 'long' armour on the British cables, that is to say that the British armour would be laid over the outside of the joint in the finished state. The lengths of the 'short' and 'long' armour wires were approximately 6·75m and 10m respectively.

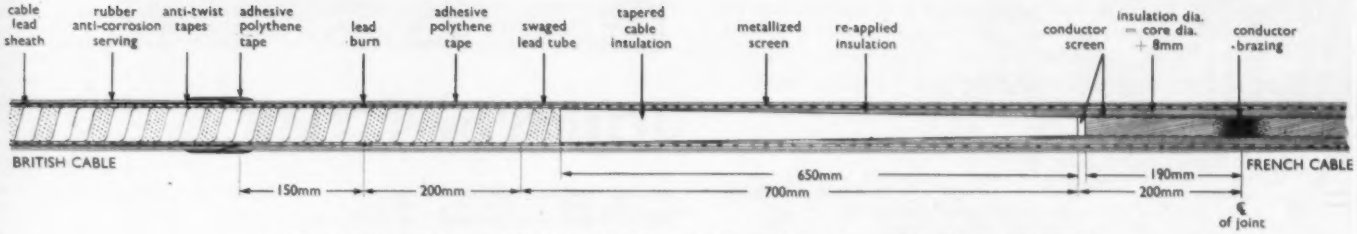


Fig. 2. The 0·525sq.in. 100kV d.c. flexible mid-Channel joint (armouring wires not shown).

The appropriate lengths of armour wires were carefully laid back, the beddings and anti-corrosion protection removed, and the cables were cut at the centre-line of the joint.

The details of the design of the joint up to the lead stage are shown in figure 2.

The conductor joint

Jointing frames were put into position and the cables cut at the centre-line of the joint before stripping to the sheath. Sections of each end were then bared to the conductor and each individual wire was splayed out and thoroughly cleaned with trichlorethylene.

Before laying the wires back into position, a wad of 'anti-migration compound' was inserted in the interstices as near as possible to the dielectric termination. The wires were snuggered back into position, layer by layer, and blown with dry nitrogen. The lead tube was slid over one of the cable ends and the conductors were fed into a steel brazing sleeve, the ends of which were lapped with asbestos string. Close to the ends of the brazing sleeve, chills were fitted, and a cold-water feed was provided throughout the operation. The sleeve was then filled with a powder flux and the brazing operation carried out. A gap of about $\frac{1}{8}$in. was left after the brazing sleeve had been fitted. On completion of the brazing, the chills and steel sleeve were removed and the centre braze was cleaned, using a file and emery paper.

Externally, the appearance of the conductor joint gave the impression that it was a solid braze about $\frac{1}{2}$in. wide into which the wires butted, but during the trials gamma radiography had shown that there was invariably a penetration of some $1\frac{1}{4}$in. on each side along the interstices of the wires.

Tapering and re-insulation

The lead sheaths were removed and the dielectric was stepped down by tearing off against a weighted piano wire, using the same technique as is used on British screened type joints.

Scene on board the "Ampère" as the cables were prepared for jointing.

The first step in re-applying the insulation was to lap layers of carbon black semi-conducting paper to link up with similar material applied to the cables.

Re-insulation was then carried out, lapping by hand 12mm and 20mm wide impregnated paper tapes first across the conductor screen and then building up, layer by layer, across the joint and up the slopes of the chamfered cable dielectric. On reaching core level, the additional papers were applied until the diameter at the centre of the joint was 8mm in excess of the core diameter. These papers were formed into a long chamfer back to the cable core screen and an aluminium foil screen was applied overall.

Swaging of the lead tube

The lead tube previously passed over one of the cable ends was next slid into position over the centre of the joint.

The swaging was carried out in the usual manner using wooden cleats, fitted with handles, of successively smaller diameters as the operation proceeded from the centre of the joint in both directions towards the cable sheath terminations. Tallow and heat were used to assist in the process. When the lead tube had been completely swaged down on to the aluminium foil screen, the tube was cut to butt with the sheaths of the cables and each face was filed to 45° to receive the metal from the lead-burning operation which was to follow.

Lead-burning

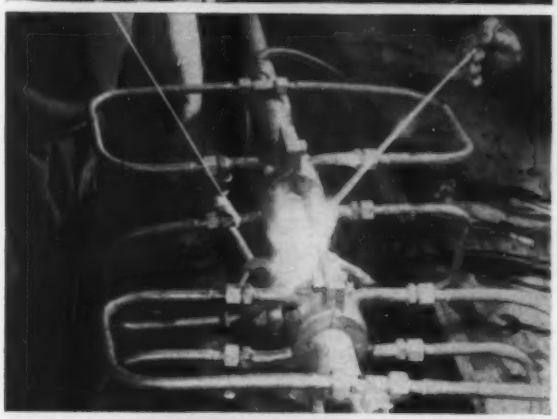
Two wooden swaging cleats were applied to each of the cables and a further cleat fixed to the centre of the joint. A welded tubular steel assembly was then fitted on to the handles of the cleats, such that it was possible to rotate both cables and the joint. Water jackets were fitted on each side of each lead burn and the burning process was commenced.

After a small section of the burn was made, the whole assembly was rotated through 45°, the process being repeated at 90°, 135°, and 180°. The remaining sections of the lead burn were carried out by rotating the whole assembly in the reverse direction. The twisting effect produced by this operation was transmitted over a distance of at least 6m on each side of the joint.

Many trials had been carried out by the French engineers and they had found this method the most satisfactory way of obtaining homogeneous lead burns. In one test they had carried out they had restricted the twisting effects to 1m on each side of the joint, after which the assembly satisfactorily withstood a test of 750kV d.c. without breakdown.

Armour-lead bond and anti-corrosion serving

The design of joint decided upon incorporated a bond connected between the lead tube of the joint and the outer layers of armour wires. The bond was of tinned steel braid and the next phase of the operation was to lap a turn of the braid round the lead and plumb the bond into position with the ends left free.



Stages in jointing the British and French cross-Channel power cables.

Top: **Cleaning the conductors.**

Centre: **Brazing the conductors.**

Bottom: **Binding down the lead/armour bond.**

Rubber cement was then applied round the plumb and layers of adhesive polythene tape were lapped across the whole length of the joint and extended to overlap on to the rubber anti-corrosion serving of the British cables and over the extruded polythene tube of the French cables. The tape was applied with a half-lap to a thickness of approximately 5mm.

The jute bedding from the original cable ends was next re-applied over the polythene taping, the ends of the armour bond again being left out in order subsequently to make the connection to the armour.

Armouring and serving

The principle used in armouring over the joint was that of the overlaid splice, which has been common practice in submarine cable installations for many years.

First, the inner, or short, armouring wires were replaced over the joint as nearly as possible in their original lay. As the operation proceeded from the French cable across the joint, whippings of steel wire were applied over the armour wires for a length of about 2in. at 1m intervals. The individual steel armouring wires were cleaned for a distance of 1ft on each side of the centre line and a turn of each end of the steel braid was lightly secured with steel wire binders. The ends of the inner armour wires were taped with adhesive p.v.c. tape.

The outer armour wires were then replaced, using a similar method, and a 3in. whipping of steel wire was applied every metre. The wires on the centre of the joint were cleaned and the armour bond was finally lapped round the armour, to be totally enclosed with a long binding of steel wire and liberally coated with bitumen.

Over a distance of 1m the free ends of the outer armour wires were cut back in 3in. steps, in groups of three wires, and the ends secured.

The final jointing operation consisted of the application of a binding of heavy jute, tightly applied with serving mallets in a close lay over the whole length of the reconstituted armouring and extending for a distance of about 20cm on to each of the cables.

Final Operations

It remained only for the two loops of cables containing the joints to be lowered on to the sea bed. To achieve this, the ship was moved slowly astern on its slackened mooring lines and the loops were passed along the deck and finally over the bow sheaves.

Control was effected by attaching lines to various points along the cables.

The operation was conducted with due ceremony, and the French cable-hands produced a Union Jack, a Tricolor, and a bouquet which were affixed to the cables as they made their descent to the sea bed.

Testing

Final acceptance tests for one hour at both negative and positive polarities at 200kV d.c. were applied from the French converter station at Echingen.

End of a successful operation: the jointed cables being lowered on to the sea bed from the "Ampère".

PROGRESS IN BRITISH STANDARDS

AMONG ITEMS OF interest presented in the Annual Report 1960–1 of the British Standards Institution, covering the period from April 1960 to March 1961, are mentions of electrical progress in many fields.

A revision of **B.S. 542—Cable glands and sealing boxes,** states the report, would concentrate on mining requirements for compound-filled types, although the standard would be open to adoption by 'surface' industries. The Electrical Research Association was investigating appropriate creepage and clearance distances in relation to this standard.

The activities of the British Electrical Approvals Board for Domestic Appliances had caused urgent attention to be given to standards for flexible cords. With the safety aspects of domestic appliances particularly in mind, a sub-committee was authorized to draft a new specification.

Work had also started on a British Standard for polyphase plugs and socket outlets for industrial power supplies, based on the recent **C.E.E. Publication 17—Plugs, socket outlets and couplers for industrial purposes.**

Also in the preliminary stages was a Standard dealing with cables insulated with varnished woven polyethylene terephthalate.

The Codes of Practice Committee for Electrical Engineering was preparing a draft code on electrical installations in which it was hoped to include certain clauses on floor-warming.

A new draft code on earthing had been prepared by this committee, following general circulation of the original draft code. It was considered that while provision of the clauses dealing with testing of earth-leakage circuit-breakers was fully justified as a statement of desirable practice, the clauses were not necessarily a statement of widely accepted practice. The views of a number of Electricity Boards and electrical contractors were being sought.

Drafting of a code for the installation and maintenance of dust-tight electrical equipment had begun, upon the appearance of the draft B.S. on this type of equipment.

A standards committee had also made good progress in preparing **B.S. 1991 : Part 6—Letter symbols, signs and abbreviations—Electrical engineering.** Being issued shortly were **Part 2—Chemical engineering, nuclear science and applied chemistry, Part 3—Fluid mechanics, Part 4—Structures, materials and soil mechanics,** and **Part 5—Heat engines.** A comprehensive revision of **Part 1—General** was being planned.

International activities concerned with standardization are also reported. The I.S.O. (International Organization for Standardization) committee on aircraft had, among other things, modified earlier proposals relating to dimensions, ratings, and performance requirements for aircraft electrical cables.

An International Electrotechnical Commission committee on graphical symbols met in Paris in June 1961, and recommended the publication of documents on graphical symbols dealing with a variety of subjects, including lines for the transmission and distribution of energy. Recommendations on graphical symbols actually published during the year were **Publication 117–1,** dealing with kinds of current, distribution systems, methods of connection, and circuit elements, and **Publication 117–2,** concerning machines, transformers, primary cells, and accumulators.

The scope of the committee on electric cables had been widened to include rubber-insulated and plastics-insulated cables as well as paper-insulated cables. It would also deal with dimensions as well as tests. A document on cable selection, for which the U.K. was mainly responsible, had been circulated for comment.

The work carried out by the C.E.E. (International Commission on Rules for Approval of Electrical Equipment) included draft specifications for steel conduit and p.v.c. conduit and fittings; the review of **Publication 7—Plugs and socket outlets for domestic and similar purposes;** the preparation of a draft specification for lighting fittings for tungsten filament lamps; and a review of **Publication 13—Polyvinyl chloride cables and flexible cords,** to make it more acceptable to member countries in place of their national specifications.

Drake & Gorham—75 Years

CONGRATULATIONS TO MESSRS Drake & Gorham Ltd, electrical manufacturers and contractors, on reaching their seventy-fifth year in the industry.

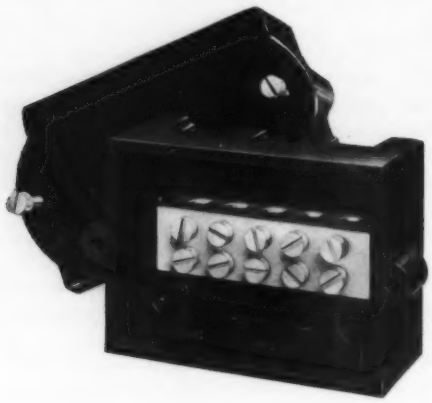
The firm began when Bernard M. Drake commenced business as an electrical engineer in 1886. Shortly after, he was joined by John Marshall Gorham. They specialized in the installation of small generating sets in country mansions. The most famous of their early installations was undoubtedly the electric lighting of Chatsworth, the Derbyshire seat of the Duke of Devonshire, in 1893.

The present century saw the company branch out into the manufacture of electrical equipment. Today their name is as well known as any in the industry.

When Mr Bernard Drake died in 1931, his son, Mr R. H. M. Drake, became chairman and managing director. Mr W. Parker is co-managing director of the company.

A E I CABLE DIVISION is at the
Building Exhibition (Olympia, 15-29 Nov.)
ROW T STAND 356/7

New Five-way Connector Box



A USEFUL ADDITION to the AEI 'Henley' range of single-pole connector boxes is now being marketed.

It is a five-way connector box for phase or neutral connections suitable for conductor sizes up to 0.06sq.in., double incoming at the bottom and triple outgoing at the top.

The connector block itself is of tinned brass, and the conductor entries are bell-mouthed. Two brass pinching screws are fitted for each conductor.

The block is contained in a robust moulded case with a knockout diaphragm at each cable entry. The design gives a clearance of $\frac{1}{2}$in. between connector block and knockouts. Provision is made for sealing the box.

Dimensions of the box are $3\frac{3}{4}$in. by $2\frac{1}{8}$in. by $1\frac{7}{16}$in. deep. It is obtainable from AEI Cable Division depots.

LEAD SHEATHING BOOKLETS

FIRST TWO BOOKLETS of a proposed new series by the Lead Development Association are now available. The series is being produced to supply accurate and up-to-date information on various aspects of the manufacture and use of lead for cable sheathing.

The first booklet of the series is an attractive 16-page production entitled *Production, properties and uses of lead cable sheathing*. The booklet briefly reviews the versatility and general application of lead and lead alloys in different types of cable.

The second publication, *Alloy characteristics and applications*, discusses specific requirements of the lead sheath and includes eight information sheets giving composition, characteristics, and properties of un-alloyed lead and different alloys.

Both booklets may be obtained upon request from the Lead Development Association, 34 Berkeley Square, London, W.1.

Wiring History since 1870

DO YOU CONSIDER that the single-cord pull switch is a modern invention? It was the subject of three patents in 1886. Was the term 'Tumler' switch, much used in the 'nineties, synonymous with 'Tumbler', or did it originally have a significance of its own?

Facts and queries of this nature can be found in an interesting book *The History of Electric Wiring** by John Mellanby. The author, a practising engineer of many years' experience, has evidently made considerable research into his fascinating subject. His book opens by describing the decade 1870–80, when the arc lamp had come into practical use and the carbon filament lamp appeared from the inventive hands of Swan and Edison. The history of electric wiring is traced from those early days to present developments in the wiring of prefabricated buildings.

The author has chosen to treat his subject by dealing first with the general historical background—the rivalry between the gas and electricity interests and the progress in wiring rules and regulations, from 1870 to 1954—in five chapters. He then follows up the beginnings and development of cables, conduit systems, and different wiring accessories in separate chapters, each of which will have some hitherto unknown fact to reveal to most of his readers.

Well-known names of historical figures and companies occur from page to page and others also, of more obscured fame, receive their share of credit for inventions and improvements by which wiring evolved from a somewhat hazardous means of conveying electric current to a safe and universally accepted system.

The book has a personal flavour. Mr Mellanby's own remarks are often very much to the point as, when dealing with ceiling roses, he comments on fittings available as late as the 1930s: "While most accessories did manage to comply, more or less, with the wiring rules, it appears that the makers of artistic fittings took a delight in designing them in such a way that compliance was impossible."

There is evidence, too, that the appearance of many accessories has stood still since original patterns were produced as long as thirty years ago.

But on the whole it can be seen that, for a new source of power and lighting which became available to the public comparatively quickly, electricity was the subject of very sound principles of practice being formulated by the pioneers of installation. There were misunderstandings of electrical theory in the early days, even by men in charge of the supply companies, as Mr Mellanby shows—a fact which may encourage the student faced today with the study of electrical engineering!

The book is a valuable record of one aspect of electrical engineering and it is, moreover, stimulating reading for anyone in the industry.

* *The History of Electric Wiring* by John Mellanby, M.A. (CANTAB.), A.M.I.E.E., M.INST.F., M.I.H.V.E. Macdonald & Co. Ltd. 244 pp. 32s. 6d.

COMPUTER TOOLS FOR THE ANALYSIS OF POWER SYSTEM PROBLEMS

Network Analysers and Electronic Computers

by A. SALZMANN, Dipl. Ing., A.M.I.E.E.

PART 1

Introduction

In the early days of the supply industry, forecasting of the performance of power systems under both load and fault conditions was not a difficult task. Analytical methods such as the reduction and back substitution methods or the application of Kirchoff's laws, and the use of hand-computing devices such as the slide rule and mechanical calculators facilitated the solution of network problems. Such tools were adequate, as generation took place with little interconnection of power stations, and transmission and distribution with little integration of networks. In addition, problems such as stability were non-existent.

However, power systems continued to grow and, with the growth, additional complex problems such as system stability emerged. Obviously, present-day widespread interconnection of networks, with their growing complexity, presents problems which cannot be solved by hand computation. Even if a solution were possible by applying an analytical method, the time spent in obtaining it, involving, for example, the solution of twenty to thirty equations, is economically not justified. Further, assumptions have to be made, because of mathematical difficulties, which may lead to inaccuracies. These considerations have led to the employment of modern computing devices such as network analysers and electronic computers for the study of steady-state a.c. networks. With the aid of these devices a wide range of problems arising from the generation, transmission, distribution, and use of electrical energy can be solved. For the study of transients, such as rate of rise of restriking voltages and similar problems, specially designed computing devices are used.

NETWORK ANALYSERS based on the miniature replica principle, or on electrical analogues, replace network calculations by direct measurement of current, voltage, watts, vars, and phase displacement between current and voltage at any point of the network. A true three-phase miniature model is not justified owing to its cost and limited application, but an analyser representing only single-phase networks gives reasonably accurate results when dealing with three-phase networks under balanced conditions. In cases of unbalance the method of symmetrical components or allied components facilitates the representation of single-phase arrangements. According to the type of system fault, the equivalent single-phase network consisting of positive, negative, and zero-phase sequence components is to be considered as an analogue of the three-phase network, and not its model. Similarly, the sum-difference method originated by Miss Edith Clarke,[1] requiring only two single-phase networks, will represent any type of fault on the analyser.

ELECTRONIC COMPUTERS solve problems by mathematical methods, giving more accurate results as compared with analysers. There are two types of electronic computers, namely digital and analogue. The former operates on numbers and the latter on continuously variable quantities represented, for example, by voltages. Illustrating these principles among non-electronic devices, a key-operating adding machine is digital while a slide rule is analogue.

The digital computer performs elementary arithmetic, being an adding device only. Nevertheless it is the speediest, most accurate, and powerful calculating tool ever invented. Compared with the desk calculating machine, where the operator controls and determines the course of calculation, the digital electronic computer does not require human intervention during the period of operation because it is an automatic sequence-controlled machine. This device is capable of making decisions, from the result of calculations, to choose between alternative courses of action during the period of calculation.

In this paper our task is to deal with computer methods in the solution of network problems arising from generation, transmission, distribution, and use of electrical energy.

1. Network analysers

Several types of analysers are available and may be divided into three groups: impedance type, resistance type, and transformer analogue type. The first group, analysers in which the system elements are represented by impedances, and the third group, in which the elements are represented by ideal transformers, are used where accurate solution of network problems is required, while the second group, resistance type analysers, has a limited application where less accurate calculation is required—for example in the determination of the short-circuit MVA of circuit-breakers based on three-phase or single-phase earth-fault current. With the first and third groups of analysers a variety of network problems can be solved. These are outlined in Table 1 overleaf.

Table 1

Problem type	*Solution on the Analyser*
System study and allied circuits problems	1. Load flow (kW and kVArs) 2. Bus-bar voltages 3. Effect of rearranging circuits and incorporating new circuit on system loading 4. Effect of temporary loss of generation and transmission circuits on system loading 5. Effect of injecting in-phase and quadrature boost voltages on system loading 6. Optimum system running conditions and load distribution 7. Optimum system losses 8. Optimum rating and tap range of transformers 9. Operational improvement from change of conductor size and system voltage 10. Effect of system unsymmetrical loading on current and voltage 11. Synchronous condensers, series and shunt capacitor requirements
Fault analysis	1. Maximum and minimum three-phase short-circuit current 2. Unsymmetrical fault-current for single and double line-to-earth fault; line-to-line fault; generator circuit fault 3. Investigation of the operation of protective relays 4. Determination of rated rupturing capacity of breakers 5. Fault current distribution and bus-bar voltage levels during faults For these studies normal load current is (a) taken into account, (b) neglected
Stability studies	1. Steady-state stability limits 2. Single-pole high-speed auto-reclosing and its effect on system stability 3. Three-pole high-speed auto-reclosing for tie lines and its effect on stability 4. Switching time for various types of faults 5. Transient stability for various types of faults with simplifying assumptions

1.1. *Impedance type analysers*[2]

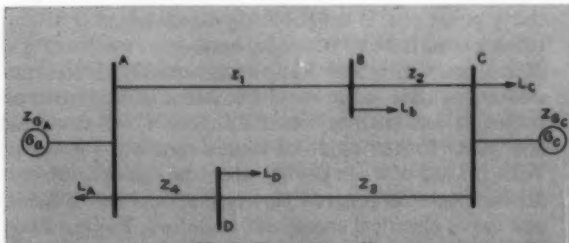
1.1.1. *Analyser elements*

Here the system components are represented by (a) impedance units comprising adjustable resistors and reactances scaled in ohms or per unit values, (b) capacitors scaled in μfd, (c) generator units, and (d) auto and coupling transformers. As an illustration, a typical network (figure 1) is used to indicate how a power system is represented on an a.c. analyser. Figure 1a shows the outline diagram, figure 1b the equivalent circuit for the system, and figure 2 the connection made on the analyser in setting up this network. Impedances of generators, transformers, and lines are represented by line units, loads by load units, but as the latter are connected usually in shunt, their ohmic value is much higher than the series impedance represented by line units.

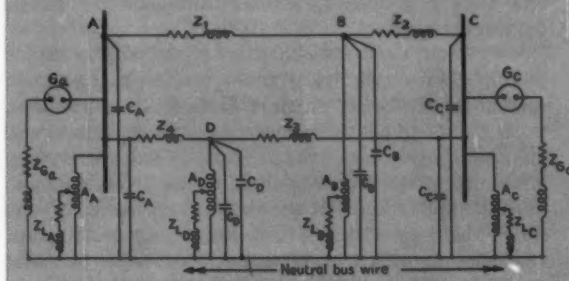
Load units are provided with voltmeters and equipped with a tapped auto-transformer called a 'load adjuster' to maintain constant power consumption during the variation of system voltage. The voltmeters are fitted with dummy pointers with the object of maintaining voltage on the load unit by means of the load adjuster during the period of variation in system voltage. This arrangement is essential, as the load on the actual network is not much affected by the variation of system voltage, but on the analyser the load varies as the square of the voltage.

Capacitor units represent the capacitance of condensers, cable and overhead lines. As the transmission line is to be considered as an equivalent 'π' circuit, half of the line capacitance is lumped on each bus-bar. Fewer capacitor units are in use if the capacitances are summated at the bus-bars.

On a.c. network analysers each power station is represented by one generator unit. The latter comprises a phase shifter (figure 3) energized from a three-phase source and connected in series to a second unit which controls the magnitude of the voltage without altering its phase. In this manner we provide single-phase output, adjustable for any phase angle and voltage magnitude. Generator impedances are represented by units connected in series with the generator unit. In order to reduce the physical dimensions of the analyser components to a reasonable size, three-phase supply usually has a frequency of the order 500–1 600c/s.



1a. Single-line system diagram.



1b. Simplified analyser diagram.

Fig. 1. Representation of a power system on an impedance type a.c. network analyser.

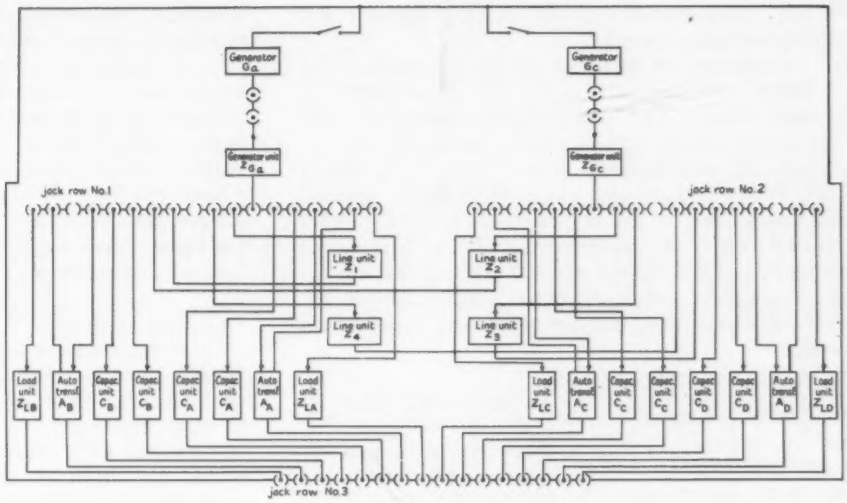


Fig. 2. The network shown in fig. 1 set up on an a.c. impedance type analyser.

Transformers are represented by a series impedance, provided that the turn ratio is the same as the ratio of the nominal voltage. However, if the turn ratio is different, as when the transformers are the part of a ring main and the product of all transformer ratios along the ring circuit is not unity, this voltage difference is represented on the analyser by auto-transformers. Finally, coupling transformers of ratio 1:1 are used to represent the effect of mutual impedance between circuits. Adjustable mutual impedances are obtained by shunting one winding of the transformer with an adjustable impedance. Further coupling transformers of ratios 1:1, 1:2, 1:$\sqrt{3}$ are provided to reproduce equivalent single-phase circuits for any combination of unbalance.

1.1.2. *Connections of analyser components and metering*

Connections are made to secure correct polarity throughout the analyser circuit. For interconnection of various elements, means must be provided to connect circuits in any combination. Units shown in figure 2 terminate in a pair of flexible cords each having a single-pole plug. Insertion of these plugs into jacks establishes connection of the unit. The polarity of each element is marked by a colour code and in figure 2 the positive terminal is denoted by a large dot on the line. For the watt-vars meter, correct polarity means indication of the direction of power flow, and for the voltmeter it is a reference for voltmeter connection.

Metering is performed by two sets of instruments, namely: (a) instruments connected permanently to the source of supply, and (b) master instruments consisting of a voltmeter, ammeter watt-vars, and phase-angle meter. Operation of current, voltage, and watt-vars switches (the latter being provided for each unit and located on the master-meter control desk) permits reading of current, voltage, watts, and vars, the instruments being connected to the selected unit. Finally, in order to make the burden of the master instruments very small, it is desirable to supply the latter with current and voltage *via* electronic amplifiers.

1.1.3. *Procedure for using impedance type analysers*[3]

Before the analyser is set up, the first step to be taken is to assemble the data, such as the impedances of system elements in complex form, transformer ratio, voltages at bus-bars, generator kW and kVAr loading, consumer loads and p.f., and capacitance of condensers, cable, and overhead lines. Obviously, the accuracy of the analyser result will depend primarily on the accuracy of system data.

The second step to be taken is to select a suitable base or scale for representing the power system on the analyser. The base, selected arbitrarily, must be low enough so that the load current will not exceed the maximum current-carrying capacity of the analyser circuits, but high enough to enable small load values on meters to

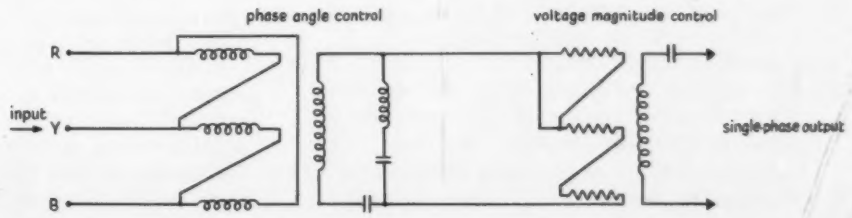


Fig. 3. Generator unit for an analyser of the impedance type.

be read. All system data are converted to this common base in per unit or per cent.

To represent electrical power systems to scale on the analyser, we select arbitrarily any two of power (MVA), current, voltage, and impedance—say power $P_s=100$ MVA and voltage $V_s=33/\sqrt{3}$kV. Current I_s and impedance Z_s are determined from P_s and V_s. Assuming that the a.c. analyser base quantities V_a and I_a, selected arbitrarily, are $V_a=50$V representing V_s, and $I_a=0{\cdot}05$A representing I_s, we can determine (1) the base ohmic value $Z_a=V_a/I_a=1\,000\,\Omega$ and (2) the scale factors k_1, k_2, k_3, and k_1k_2 required to establish the relationship between system and analyser quantities. Thus we can write:

$k_1=V_s/V_a=19\,100/50=382$;
$k_2=I_s/I_a=\{(100\times10^6)/(3\times19\,100)\}/0{\cdot}05=35\,100$;
$k_3=Z_s/Z_a=(V_sI_s)/(V_aI_s)=k_1/k_2=0{\cdot}010\,9$; and
$k_1k_2=(V_sI_s)/(V_aI_a)=P_s/P_a=382\times35\,100=134\times10^5$.

It should be emphasized that the analyser operates at a certain frequency in order to make the base ohmic value $Z_a=1\,000\,\Omega$.

As a check: System impedance in percentage is $Z_s\%=(Z_s\Omega\times100\times\text{base})/(\sqrt{3}V_s)^2\text{kV}=9{\cdot}15Z_s\Omega$ based on 100MVA and 33kV. As 100% impedance corresponds to 100MVA base because of the relationship MVA$=(100\times\text{base})/Z_s\%$ we obtain from the above equations for $Z_s=100\%$ the impedance expressed in ohms: $Z_s=10{\cdot}89\,\Omega$, which agrees with $Z_s=V_s/I_s=19\,100/1\,750=10{\cdot}89\,\Omega$. The scale factor is equal to $k_3=Z_s/Z_a=10{\cdot}89/1\,000=0{\cdot}010\,9$ which also agrees with the value given above.

Thus 50V on the analyser represents 19·1kV on the power system, 0·05A represents $100\times10^6/\sqrt{3}\times\sqrt{3}\times19{\cdot}1\times10^3=1\,750$A on the power system, $1\,000\,\Omega$ on the board represent $19\,100/1\,750=10{\cdot}89\,\Omega$ on the system, and power $I_aV_a=0{\cdot}05\times50=2{\cdot}5$VA on the analyser represents 100MVA (33·3MVA/phase). The scale for voltage is 1:660 and power 1:40 000.

Finally, the last steps to be taken for the solution of a problem are:

(i) Formulation of the problem.
(ii) Preparing a single-line diagram of the system and entering rating of generating and transmission elements and impedance data.
(iii) Setting up resistance, reactance, capacitance, and load impedance to the value shown on the single-line diagram. Notice that, since reactors on the impedance unit have some resistance, the value of the resistance to be set up on the impedance unit must be therefore less than the calculated value.
(iv) Interconnection of the network on the analyser to correspond with the single-line diagram.
(v) Adjust operating conditions.
(vi) Take readings and convert them to system values. On some analysers watt-vars meters are calibrated to read a.c. quantities directly.

Subsequent to interconnection and adjustment of the analyser elements, the generator units are energized and adjusted to phase angle and magnitude of voltage until reasonable values of volts, watt, and vars are recorded. Prior to solving network problems as outlined in Table 1, adjustment of generator and load units will be required to represent known system conditions. If, for example, a fault problem is to be solved, in which a three-phase short-circuit current at location B (figure 1) is to be determined, the fault is established by connecting, *via* a jumper, jack No. 6 (jack row No. 1) to jack row No. 3 (see figure 2), and the analyser is set up as outlined above for pre-fault conditions.

1.1.4. *Stability studies*[4]

A power system is stable in the steady state if an increase of load is accepted without loss of synchronism. In the transient state, the system is stable if, after a disturbance, operation continues without any generator falling out of step. Thus stability is a function mainly of transmission of power, speed of the voltage regulator, auto-reclosing, and speed of the protective gear. For stability studies the analyser is set up on the positive sequence network basis, as this applies to normal conditions, and such problems can be solved as (a) steady state load limits, (b) loads following system disturbances, and mechanical swing curve of generators.

However, problems mentioned under group (b) are of a transient nature and cannot be represented directly on the analyser. Here we apply the well-known indirect method, i.e. the step-by-step method representing brief steady-state conditions of the system. In this method small intervals, usually of 0·1sec, are taken so that we can assume that the accelerating forces exerted on the generator remain constant within this interval. In addition, it is assumed that the excitation of the generator during this period does not change, and neither does the governor of the prime mover. For each step (0·1sec) we determine the change in position of the rotor of each machine.

As an example: it is required to check a given fault clearance speed t_f, assuming a two-machine system operating *via* two tie lines in parallel. The object is to find out whether t_f is adequate to maintain stability and to keep the generators in synchronism during the system of period disturbance. The analyser is set as outlined above and, before the fault is applied, we record power, voltage, and phase angle of each generator. Subsequent to fault application, voltage and phase angle will be maintained at the original values but power output of the generator will be different. Calculations are made to determine, on the actual network, the angle α through which the rotor moves for a period of, say, 0·1sec. The analyser generators are then adjusted to a new angular position and power output readings are taken again. This procedure will continue until t_f has been reached. However, the step-by-step method is continued after the fault is removed in order to determine whether the system is stable, i.e. that generators return to normal or that synchronism is lost. This is illustrated by the 'swing curve' or step-by-step angle/time curve shown in figure 4.

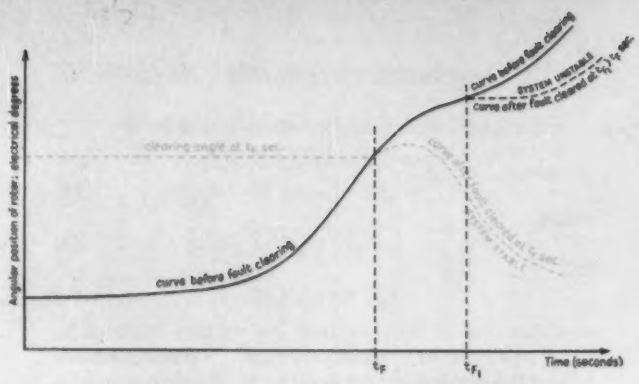


Fig. 4. Swing curve of two-machine system.

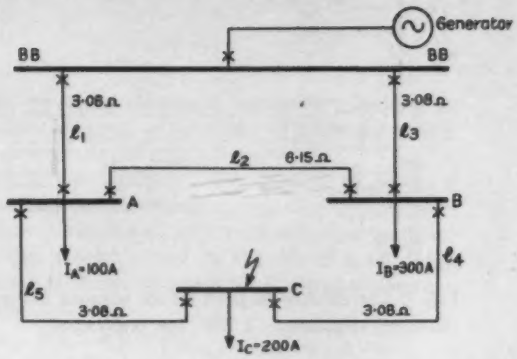


Fig. 5. Single-line diagram of three-phase power system.

Alternatively we can determine, with the aid of the swing curve, the fault clearance time required to maintain stability for a given fault location.

Finally, it should be pointed out that the a.c. analyser is not to be confused with a transient analyser since the former is limited to operation at one frequency. Variable frequency studies, such as those concerning the flow of harmonics in power systems, overvoltage due to switching operation, and the rate of rise of restriking voltages, are solved on the transient analyser. The latter is capable of operating over a wide range of frequencies but has to be adjusted to values corresponding to the frequency to be studied. Such an analyser, with a variable frequency supply of 159–15 900c/s, has been built by the Electrical Research Association. Obviously, transient stability determined on a transient analyser is carried out by the direct method.

1.2. *Resistance type analyser*

Resistance type analysers are restricted to the solution of problems such as (a) fault levels, rupturing capacity, and the rating of circuit-breakers, and (b) load flow. This type of analyser is to be considered as an analogue calculator consisting of a number of decade resistors. Each unit (representing a system element) terminates in a pair of flexible cords having a single-pole plug. Insertion of this plug into a jack makes the connection of the unit. If the ratio X/R of any system element is high, such as for overhead lines above 66kV, the reactance of the circuit is used in setting up the d.c. board. However, if the resistance is large compared with the impedance, as in low-voltage networks, the impedance value should be taken into account in setting up the analyser. The error caused by adding analyser elements algebraically is small provided that the difference in the impedance angle of various system elements is small. For short-circuit studies, maximum accuracy is achieved if the e.m.f.s of the generators located in various power stations are equal in phase and magnitude, having uniform ratios of X/R; while for load studies, uniform power factors and X/R ratios are required.

As an example, let us consider the network shown in figure 5. Our task is to illustrate in figure 6 how to set up this circuit on the analyser for a three-phase fault at location 'C'. (Fault plug inserted in jack row C.) For a single line-to-earth fault, assuming a solidly earthed system and zero fault resistance, the fault current is

$$I_f = 3V_{ph}/(2Z_1+Z_0) \quad \ldots\ldots\ldots\ldots (1)$$

This is obtained on the board if the assembly of resistors representing the positive sequence network, Z_1, and set up for a three-phase short-circuit, is increased to

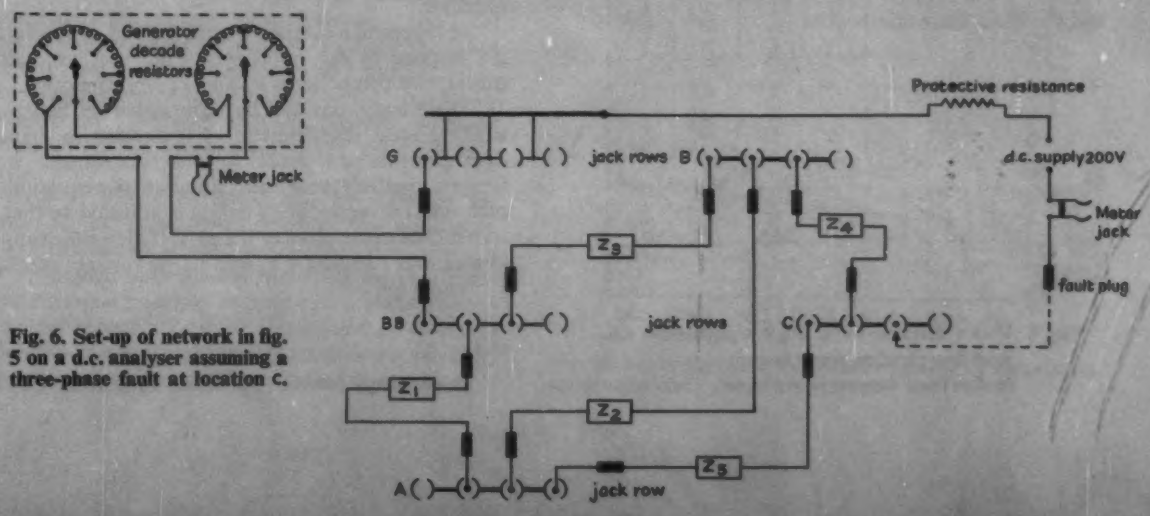


Fig. 6. Set-up of network in fig. 5 on a d.c. analyser assuming a three-phase fault at location C.

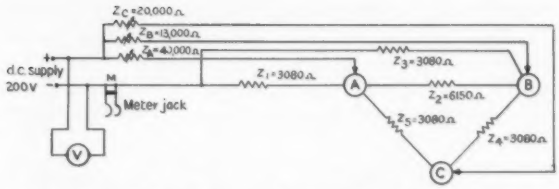


Fig. 7. Current-flow diagram for the network shown in fig. 5. (Analyser impedance = 1 000 × line impedance.)

twice its value, $2Z_1$, and if this modified d.c. board, representing positive and negative sequence networks, is connected in series with a second d.c. calculator representing the zero sequence network Z_0.

Regarding current-flow studies, a less accurate solution of this problem is possible by injecting a small current proportional to the substation load current. How this is achieved for the circuit in figure 5 is illustrated in figure 7: each load unit is adjusted to give the desired load current. For example, the ohmic value for the load unit Z_A representing $I_A=100$A is equal to Z_A=volts/amperes=200/0·005=40 000Ω, assuming analyser voltage 200V and full-scale deflection of the milliammeter M of 25mA=500A. As a check: current obtained by dividing applied voltage by the calculated resistance of the equivalent network must be equal to the current measured at location M, yielding the arithmetical sum of substation currents.

An accurate solution of load-flow problems, first suggested by Hahn,[5] can be achieved by setting up two independent networks representing the in-phase resistance component and quadrature reactive component of each system element. Thus it will be required to combine power flow in two analyser circuits in order to determine the corresponding flow in the power system.

Consider the system impedance $Z=R+jX$ given in complex form. The applied voltage ΔV, which is in effect the voltage-drop between the sending and receiving end voltages (V_s-V_r) as shown in figure 8, is equal to $\Delta V=V_p+jV_q$,
where the in-phase component

$$V_p=I_pR-I_qX \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

and the quadrature component

$$V_q=I_pX+I_qR \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

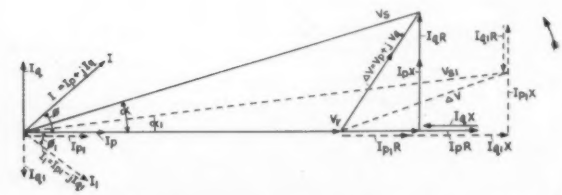


Fig. 8. Vector diagram for a single transmission o.h.l. solid lines: leading power factor; broken lines: lagging power factor.

Equations 2 and 3 can be written in the form

$$V_p=I_p[R-I_q/I_p(X)]=I_pr_p \quad \ldots\ldots\ldots\ldots(4)$$

$$V_q=I_q[R+I_p/I_q(X)]=I_qx_q \quad \ldots\ldots\ldots\ldots(5)$$

where

$$r_p=R-(I_q/I_p)X \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

and

$$x_q=R+(I_p/I_q)X \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

From this it follows that the system impedance, $Z=R+jX$, can be represented by an in-phase network r_p, and the quadrature network by x_q. Further, it will be required to guess currents I_p and I_q in order to determine r_p and x_q by trial-and-error methods. However, it is questionable whether the setting up of two separate analysers is a practical proposition if the network is complex and fed by more than two sources of supply.

Finally it should be pointed out that if the current lags behind the system voltage we obtain, according to the vector diagram, figure 8:

$$V_{p_1}=I_{p_1}R+I_{q_1}X \quad \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

$$V_{q_1}=I_{p_1}X-I_{q_1}R \quad \ldots\ldots\ldots\ldots\ldots\ldots(9)$$

1.3. *Transformer analogue analyser*

On this type of analyser, impedances of generators and transmission elements are represented by ideal transformers having adjustable ratios. Each unit is provided with electronic compensation to make it ideal. If the turn ratio is n_1/n_2 we can write

$$V_1=(n_1/n_2)V_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

which is analogous to Ohm's Law

$$V=RI \quad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

If, for example, $V_1=V$, and $n_1/n_2=R$, voltage V_2 must be equal to I according to equation 11. Thus if (n_1/n_2) is made equal to the value of system resistance R, and voltage V_1 is applied to one side of an ideal two-winding transformer, the other side will measure the current I which would flow with a voltage applied across the actual resistance. In a similar manner, reactance X can be represented by a transformer unit. It should be noted that the Blackburn analyser developed from the Mallock mathematical machine is based on this principle.[6]

To represent a complex quantity $Z=R+jX$, a voltage ΔV applied to the impedance will yield, as outlined earlier, two components V_p and V_q (see equations 2 and 3). These equations can be represented by two three-winding ideal transformers as illustrated in figure 9. Arrangements are made to interconnect the transformers to satisfy these linear simultaneous equations. In each unit the secondary winding is adjusted so that the turn ratio is made equal to R and X. If the voltage applied to windings *1* and *2* are V_1 and V_2 the voltages measured at *3* and *4* are

$$e=(a-d) \quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

and

$$f=(b+c) \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

The analogy between equations 2, 3, and 12, 13 can

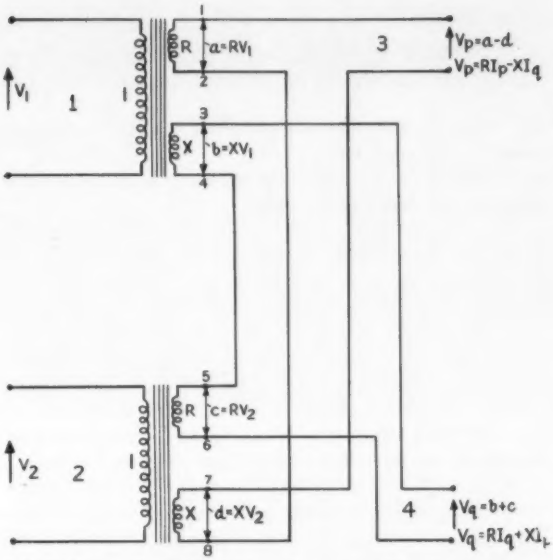


Fig. 9. Connections of ideal transformer used for the solution of simultaneous equations.

be seen if V_1 and V_2 are called I_p and I_q, and e and f are called V_p and V_q respectively.

In a similar manner other elements such as generators, transformers, loads, and capacitors, connected in series or parallel, are represented by ideal transformer units. Loads are represented by admittances instead of impedances in order to extend the range of the unit.

An analogue to represent admittance is derived as follows:

As outlined earlier, let

$$\Delta V=V_p+\mathrm{j}V_q=(I_p+\mathrm{j}I_q)(R+\mathrm{j}X).$$

Rewriting this equation, we get

$$(V_p+\mathrm{j}V_q)/(R+\mathrm{j}X)=I_p+\mathrm{j}I_q.$$

Multiplying by $(R-\mathrm{j}X)$ we obtain:

$(V_p+\mathrm{j}V_q)[\{R/(R^2+X^2)\}+\mathrm{j}\{X/(R^2+X^2)\}]=I_p+\mathrm{j}I_q$ or $(V_p+\mathrm{j}V_q)(G-\mathrm{j}B)=I_p+\mathrm{j}I_q$, whence $I_p=GV_p+BV_q$; $I_q=-BV_p+GV_q$. It follows that any admittance is represented on the analyser by substituting I_p and I_q for V_p and V_q and connecting terminals *2* to *7* and *3* to *5*. See figure 9. (Compare these equations with 2 and 3.)[7]

From inspection of figure 9 it follows that four separate circuits are provided and the analyser voltages, assumed co-phasal, are supplied from a single-phase source.

Finally it should be noted that by reversing the polarity of the transformer winding the impedance $\pm R\pm\mathrm{j}X$ can be represented on the calculator. This is a great advantage in analysers operating on the transformer analogue principle. Negative resistances, capacitances, and generators can be represented by reversing the polarity of the corresponding transformer winding. In an impedance type analyser a negative resistance is obtainable by using electronic valves or a generator. Further, the solution of complex and non-complex matrices and matrix inversion is possible.

The Blackburn analyser is also capable of solving a number of linear simultaneous equations, provided there are a sufficient number of units available. For example, six equations can be solved by the use of seven ideal transformers as shown in figure 10. If the equations are given in the form:

$$\begin{aligned}
a_1x_1+b_1x_2+c_1x_3+d_1x_4+e_1x_5+f_1x_6+g_1&=0\\
a_2x_1+b_2x_2+c_2x_3+d_2x_4+e_2x_5+f_2x_6+g_2&=0\\
a_3x_1+b_3x_2+c_3x_3+d_3x_4+e_3x_5+f_3x_6+g_3&=0\\
a_4x_1+b_4x_2+c_4x_3+d_4x_4+e_4x_5+f_4x_6+g_4&=0\\
a_5x_1+b_5x_2+c_5x_3+d_5x_4+e_5x_5+f_5x_6+g_5&=0\\
a_6x_1+b_6x_2+c_6x_3+d_6x_4+e_6x_5+f_6x_6+g_6&=0
\end{aligned}$$

and in each transformer the secondary windings are adjusted so that the turn ratios are equal to the constant coefficients a_1, a_2, etc., then if unity voltage is applied to transformer No. 7, voltages x_1, x_2, x_3, x_4, x_5, x_6 are measured across the terminals of the corresponding transformers.

Summing up, several types of analysers are available. Their principle is the same but they differ from one

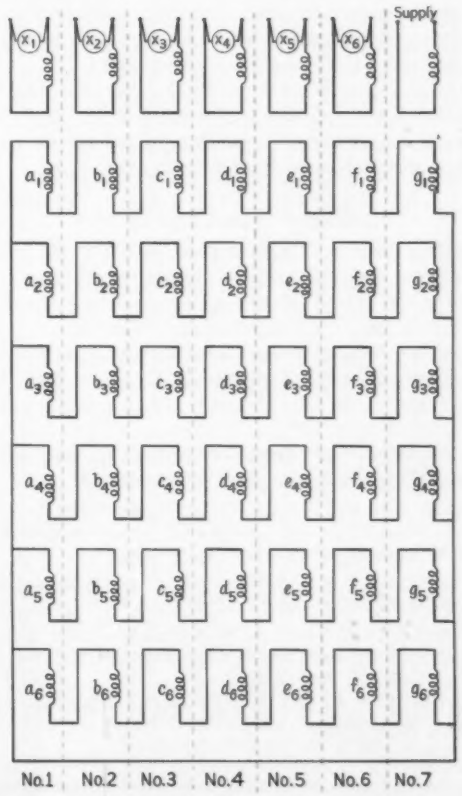

Supply
x_1
x_2
x_3
x_4
x_5
x_6
a_1 b_1 c_1 d_1 e_1 f_1 g_1
a_2 b_2 c_2 d_2 e_2 f_2 g_2
a_3 b_3 c_3 d_3 e_3 f_3 g_3
a_4 b_4 c_4 d_4 e_4 f_4 g_4
a_5 b_5 c_5 d_5 e_5 f_5 g_5
a_6 b_6 c_6 d_6 e_6 f_6 g_6
No.1 No.2 No.3 No.4 No.5 No.6 No.7

Fig. 10. Connections of transformers employed for the solution of six equations.

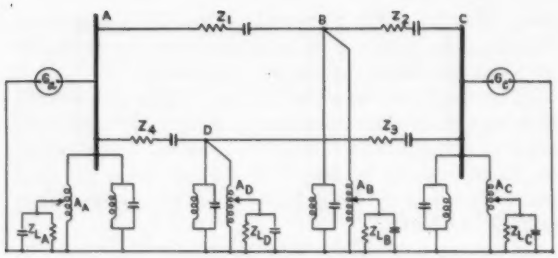


Fig. 11. System representation of the network shown in fig. 1 on the conjugate impedance analyser.

another in regard to the component representing the actual network. It is beyond the scope of this paper to discuss all the analysers in general use, but it is worth noting in particular two computing devices—the conjugate-impedance network analyser, and the dual analyser, both operating at 50c/s.

On the conjugate type,[8] sponsored by the Central Electricity Generating Board, and the Electricity Boards, units of the conventional analyser such as series R and L are converted into series R and C; shunt C into parallel C, L; and load units series R, L, into parallel R, C networks operating at lagging power factor. This is shown in figure 11, representing the equivalent analyser circuit of the network in figure 1. Note that the capacitances and conductances are lumped at the bus-bars.

On the second type, the dual analyser[9] units from series R, L are converted into shunt R, C; loads from shunt R, L into series R, C; shunt C into series L; and the voltage sources become current sources.

REFERENCES FOR PART 1

1. CLARKE, Miss E. *Circuit analysis of A.C. power systems*, Chapman and Hall, London, 1950.
2. MILES, J. G. Analogue methods in the solution of engineering problems, *M.V. Gazette*, Nov. 1953, p. 108.
3. LYON, G. Some experience with the British A.C. network analyser, *Journal I.E.E.*, 1950, vol. 97, part 11, p. 697.
4. KIMBARK, E. W. *Power System Stability*, vol. 1, ch. v, J. Wiley & Sons, 1948.
5. HAHN, W. C. Load studies on the D.C. calculating table, *General Electric Review*, 1931, pp. 444 and 482.
6. BANKS, J. H. and PARTON, K. C. The use of the Blackburn A.C. analyser in the analysis of power system faults, *I.E.E. Monograph No.* 174*S*, April 1956.
7. FITZPATRICK, J. A. and PARTON, K. C. The Witton network analyser, *G.E.C. Journal*, Oct. 1958, p. 201.
8. CASSON, W. and HALES, A. W. A conjugate impedance network analyser operating at 50c/s, *Journal I.E.E.*, vol. 105, part A, no. 21, June 1958.
9. NELLIST, B. D. Duality principle analyser, *Electrical Times*, 6 June 1957, p. 899.

Part 2 of this article, dealing with electronic computers, will appear in the January 1962 issue of ELECTRICAL DISTRIBUTION.

New British Standards

B.S. 156 : Part 1 : 1961—Enamelled copper conductors (Oleo-resinous enamel)
B.S. 1844 : Part 1 : 1961—Enamelled copper conductors (Enamel with vinyl acetate base)

In these revised editions of two established British Standards for enamelled winding wire, changes made by amendments published since the previous editions appeared have been incorporated, and some further changes made.

Prices: B.S. 156 : Part 1, 7*s.* 6*d.*
B.S. 1844 : Part 1, 8*s.* 6*d.*

B.S. 158:1961 (Revised)—Marking and arrangement of switchgear bus-bars main connections and small wiring

A revision of the 1938 edition of B.S. 158 has simplified considerably the future marking of switchgear bus-bars main connections and small wiring.

The colours now prescribed do not involve stripes, and white is no longer included as an alternative to yellow for polyphase markings. Colours for main connections and small wiring have been brought closely into line and the roles played by green and black are different in the new edition.

The new requirements will call for changes in the British Standards for electric cables and in the current regulations for electrical equipment of buildings.

An appendix to the revised specifications gives guidance on the marking of small wiring and includes reference to one system of functional marking.

Price 5*s.* 0*d.*

B.S. 2484:1961—Cable covers, concrete and earthenware

Advances in the technique of cable-laying, whereby several single-core cables are laid side by side in preference to the use of a multicore cable, have necessitated the use of wider cable covers, as it is not entirely satisfactory to lay narrow ones side by side.

To meet the needs of these new methods, B.S. 2484 has been revised to include wider covers in the range. At the same time a shorter length of cover has been introduced to provide for the modern practice of negotiating curves and bends by short-length straight covers in preference to using radiused covers, as this simplifies both ordering and stock-keeping.

Account has also been taken of the results of research by the C.E.G.B. into the use of pulverized fuel ash in concrete mixes by allowing for a proportion of this 'fly ash' to be used in concrete covers with the consent of the purchaser. At present there is no British Standard for this material, but its preparation has been authorized.

Price 6*s.* 0*d.*

Copies of these Standards may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1. (Postage extra to non-subscribers.)

West Country Supergrid Work

Terminations at Hinkley Point substation, adjacent to the nuclear power station. Tower in the foreground carries the circuits from Taunton to the two ST terminals on the left. The terminal towers on the right serve the Hinkley Point–Melksham line.

SEVENTEEN MILES OF 275/400kV overhead line construction have been completed by AEI Construction Division in Somerset for the C.E.G.B. Western Division. The line ties in Hinkley Point nuclear power station to the Supergrid, and is part of a new West of England link completing the Melksham–Hinkley Point–Taunton–Exeter routes.

Problems confronting the Central Electricity Generating Board in planning this line were twofold.

Firstly, between Hinkley Point and Taunton lie the Quantock hills. It was regarded as essential that this area, one of outstanding natural beauty, should be kept free of major overhead lines. For this reason the new line follows a roughly semicircular route to the east from Hinkley Point, avoiding the Quantocks and passing close to Bridgwater before turning south to Taunton. So that, although the straight line distance between terminals is only thirteen miles, the final route is seventeen miles long.

Secondly, the agricultural land traversed by this essential transmission line along the chosen route is some of the finest in Somerset. A large proportion of the towers is therefore situated either very close to, or straddling, hedges and ditches in order to give minimum interference to cultivation.

Line construction is 275/400kV, using double-circuit towers of Blaw Knox design.

The most interesting aspects of the contract are, perhaps, to be found at the terminations. At Hinkley Point the line terminates at a substation near the nuclear power station which is under construction. From a final double-circuit tension tower, conductors are taken to two single-circuit ST type towers (the two ST towers on the left of the illustration above). The earthwire is strung over one circuit only between the bifurcating tower and the terminals, and then from terminal to terminal. This is normal practice when the terminals are close and the circuit spacing over the span is thus small.

At Taunton the circuits are arranged in a tee junction just outside the substation, resulting in Hinkley Point–Exeter, Hinkley Point–Taunton, and Taunton–Exeter circuits. The DJX type junction tower used to obtain this arrangement is shown in the second illustration. The Taunton–Exeter circuit is being operated at 132kV; the other circuits are working at 275kV, but all will be re-insulated for eventual 400kV transmission.

Some modifications to an existing 132kV line at Taunton were also carried out by the Construction Division. A new terminal tower with supporting steelwork for sealing ends and voltage transformers was erected and existing conductors were terminated on the tower, in order to provide a cable entry for the circuits from East Yelland into Taunton substation.

The Taunton DJX tower which carries circuits from Hinkley Point and Exeter into the substation (out of the picture to the right) and provides a through-circuit from Exeter to Hinkley Point. The terminal tower on the left is the 132kV tower with sealing ends and voltage transformers mentioned in the final paragraph of this article.

EXPANDING HORIZONS IN COMMUNICATIONS

1961-2 Faraday Lecture

THE FARADAY LECTURES, given each year by an eminent electrical engineer, are intended primarily for a non-technical audience, but they are unfailingly interesting expositions of the chosen subject.

The 1961–2 lecture is entitled *Expanding Horizons in Communications* and it will be presented at the centres listed (right) by Mr D. A. Barron, M.SC., M.I.E.E., deputy engineer-in-chief of the British Post Office.

A member of the I.E.E. Council and a member of the committee of the Electronics and Communications Section of the Institution, Mr Barron presented to the Institution in 1958 a paper, *Subscriber Trunk Dialling*, which attracted very great interest.

His Faraday Lecture in which, like all of its kind, the spoken word is augmented by demonstrations, reviews the progress which has resulted in modern telephony and provides a glimpse into the future of the science.

Opening with an explanation of the means available for automatically connecting any two subscribers, the lecturer demonstrates the principles of local, national, and automatic switching and explains how a local telephone connection can be built up into a world-wide telephone system controlled by the subscriber.

Next the interconnection of telegraph and telephone exchanges and the development of cables are discussed. But the high cost of present large-capacity cables has in turn encouraged the development of multi-channel radio systems, operating by means of radio beams directed from point to point and providing a large capacity for telephone and telegraph working and capacity for television programmes. Even these are inadequate for inter-city systems and attention is now concentrated on the development of hollow metal tubes for guiding electric waves from the sending to the receiving point. These tubes have a capacity for simultaneous conversations, even simultaneous television programmes, far exceeding anything presently available.

For intercontinental communication, radio systems of small traffic capacity are steadily being supplanted by undersea cables with reliable built-in amplifying units every thirty miles or so.

Radio engineers have recently developed a new medium-range radio system that exploits the scattering of beams in the atmospheric envelope of the earth to provide a moderate-capacity multi-channel link over a few hundred miles without the need for intervening repeating stations.

Like others, the telecommunications engineer is looking into space. He sees an artificial satellite, poised high above Earth, ready to receive a radio beam directed on to it from one point on the globe and able to redirect the beam to another point, spanning an ocean or a continent in a single hop. Such a system, although high in cost, will have a vast traffic capacity and will bring trans-oceanic intercontinental television within reach.

Lecture Centres and Dates

Bristol (Colston Hall)	21 November 1961
Cardiff (Sophia Gardens Pavilion)	23 November 1961
Birmingham (Town Hall)	2 January 1962
Stoke-on-Trent (Hanley Town Hall)	4 January 1962
Nottingham (Albert Hall)	25 January 1962
Sheffield (City Hall)	30 January 1962
Southampton (Guild Hall)	6 February 1962
London (Central Hall)	14 February 1962
Newcastle (City Hall)	20 February 1962
Liverpool (Philharmonic Hall)	1 March 1962
Belfast (Sir Wm Whitla Hall, The Queen's University)	7 March 1962
Glasgow (St Andrews Hall)	29 March 1962

E.I.B.A. Report

Increasing Responsibilities

THE 1961 YEARBOOK of the Electrical Industries' Benevolent Association presents an encouraging picture of help given to 1 160 applicants during 1960. Aid was given to staff people in every section of the electrical industry.

Counting dependants, more than 2 400 people received help, and over £64 000 was given to them in money grants alone. Monetary help apart, the record is one of the kind of assistance which money cannot give—of sound advice and aid of a practical nature.

Against figures for 1959, the number of people who benefited rose by 8%, but the Association's income increased by only 6%. Thus the Association is dependent to some extent on its voluntary income—money from collections, functions, legacies, and so on—to meet its day-to-day expenses. It would like to see a larger subscription income in order to give its voluntary income towards new developments.

A third of the Association's help goes to the aged, more than a quarter to widows with children, and more than a fifth to cases of illness not falling within these categories. Its work has increased eightfold since 1945.

One of the 'new developments' is the new extension at Broome Park, the E.I.B.A.'s home for retired people, which hitherto has had accommodation for twenty-seven residents. Fifteen new bed-sitting rooms will be provided and the amenities of the existing building will be improved. Still further income is required in order to finance this £30 000 extensions and improvements scheme, and the Association appeals to the supply industry to help towards its cost.

BACK TO AGECROFT

IN 1956, AEI Construction Division engineers, then members of the old Henley Contract Department, installed the first 132kV three-core oil-filled cable in the United Kingdom at Agecroft, Manchester. When they returned to Agecroft recently to undertake another 132kV cable contract they were in familiar surroundings.

The work on this occasion was in the Salford district of the city where a run of two oil-filled cables and pilot cables was installed for the C.E.G.B., North West, Merseyside, and North Wales Region.

The cables follow a 2¼-mile route between Agecroft 132kV double bus-bar substation and a new 132kV substation at Frederick Road. Both substations are situated by the Manchester, Bolton, and Bury Canal, and the cables run roughly parallel with the canal, but some distance away, through factory grounds and a built-up area. They will be used to feed from the grid at Agecroft two 132/33kV 45MVA transformers at Frederick Road which will supply a new North Western Electricity Board substation. The substation is needed in order to relieve the North Western Electricity Board's 33kV cable network fed from Agecroft and the grid transformers there, and also to cater for future load growth.

▲ One of the joint bays as jointing of the oil-filled cables nears completion.

Illustration below shows one of the 0.4sq.in. feeders being pulled out.

The oil-filled feeder cables were 0·4sq.in. 3-core compacted conductors, paper-insulated lead alloy sheathed, tin bronze reinforced, with anti-corrosion finish. Laid with them were two pilot cables of 7/·029in. 9-core polythene-insulated, p.v.c. sheathed, single wire armoured and p.v.c. covered construction, and a 1/·044in. 12-pair telephone cable of similar construction.

The route profile enabled the oil-feed tanks to be located at the Agecroft termination, with gauges fitted to give indication of low oil pressure. Outdoor vertical type sealing ends terminate the oil-filled cables, the cores being splayed at trifurcating boxes.

The heavily built-up area along the route contained a considerable number of gas, water, and electricity services beneath the roads and footpaths, and the problem of accommodating the five new cables, which required a trench about 3ft wide, presented quite a headache.

A somewhat bizarre incident, indirectly traceable to the contract, was the "removal" by local schoolchildren of a reservoir from one of the road lamps. Not content with this, they lit it and posted it through their school letterbox, effectively setting the school on fire!

? PROBLEM CIRCLE

July Overseas Competition

Overseas readers have a fair share of space this month. The reason lies in **Problem No. 8,** the grocer's scales problem, which we 'dispatched' on this page in the September issue—or so we thought! But two overseas readers obtained different solutions, and one of them was the first to be opened from the many entries received—he is **Mr M. Singer, Haifa, 6 Frishman Street, Israel.** This reader, and **Mr R. S. Malviya of the M.P. Electricity Board, Jabalpur, M.P., India,** came up with weights of 4, 5, 17, 51, and 153lb which can be used to weigh up to 227lb—25lb more than the given solution of 202lb. They are quite correct, too.

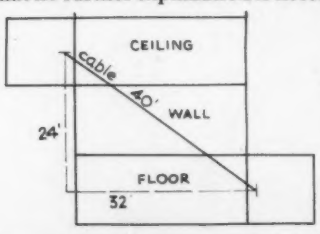
One point to note regarding the previous solution and the 'new' one. The solution of 202lb, it will be noted, uses **all** the weights given with the answer to the problem= 1+5+15+45+135=201lb, to weigh 202lb (remember that one pan was 1lb heavier than the other) whereas the weights 4, 5, 17, 51, and 153lb given with the 227lb solution total 230lb and in fact 228lb and 230lb cannot be weighed, although 229lb and 231lb can. The former is therefore a more 'perfect' solution, but the wording of the problem allows our overseas friends to be correct.

We are therefore awarding the £1 10s. prize to **Mr Singer** and a consolation prize to **Mr Malviya** and also to the reader who sent the first overseas solution opened giving the 202lb answer: he is **Mr W. Bertwell, 46 Marr Avenue, Oakland 11, California, U.S.A.**

Prize for the word sum, **Problem No. 7,** goes to **Mr R. H. Marsden, 174 Darlington Road, Miramar, Wellington E4, New Zealand.**

September Problems

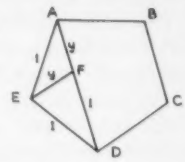
The solution to **Problem No. 9,** the dilemma of the electrician and his cable, can be so simply shown by means of the development of the room produced here that no further explanation is necessary. To some readers



it apparently proved easy: others, as we have reason to know from echoes of pleas that reached the editorial office and from humorous comments added to solutions submitted, drove themselves frantic trying to solve it. Our thanks go to the reader in India who submitted the original.

Winner of the prize for this problem is **Mr E. W. Roberts, 73 Pondfield Crescent, St Albans, Herts.**

Problem No. 10 produced some interesting methods to show that $\cos 36° = (1+\sqrt{5})/4$. Some plumped for complicated constructions, some started from $\sin 5\theta = 0$ and some used a pentagon as their basic figure. One of the neatest solutions came from **Mr C. T. Rivington,** of Essex, who chose the pentagon of side 1 unit (see diagram) and proceeded as follows:



F is a point on AD such that DF=DE=1. Since AED=108°, EAD=EDA=36°, DEF=DFE=72°. Hence EFA=108°. Let FA=y. From similar Δs FAE, EDA:

$$AE/EF = DA/AE \text{ or } 1/y = (1+y)/1$$

thus $y^2+y-1=0$ and, since y cannot be negative,

$$y = (-1+\sqrt{5})/2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Now $AD = 2ED\cos 36 = 2\cos 36 = 1+y$

$\therefore \cos 36 = (1+y)/2 = (1+\sqrt{5})/4$ from (1).

Correct solution first opened was from **Mr C. F. Mitchell, 46 Woodleigh Gardens, Whitchurch, Bristol 4,** who chose a *tortuous* method and ended his letter "there *must* be an easier way than this!"

November Problems

Problem No. 11

The circle can, by means of ruler and compasses only, be divided into a number of equal segments. In how many ways can I divide the circle into an ODD number of equal segments, given that I set myself a maximum of 99 segments, to avoid physical exhaustion and mental aberration. Remember—ruler and compasses only to be used.

Problem No. 12

An easy one? complete the multiplication sum. Six threes are 18—carry on!

Note: each row of figures is incomplete; the dots represent an incomplete row of figures; 44.....18 is one row; and finally the result is a 13-figure number!

```
          9053
           956
44        18
718
...
5
     424
     442
```

Solutions to Problem Circle

Solutions to the Problems 11 and 12 should be sent to the Editor, ELECTRICAL DISTRIBUTION, Crown House, Aldwych, London, W.C.2. **Envelopes should be marked 'Problem Circle'.** *Closing Dates:* 20 December 1961 for competitors resident in Great Britain, Northern Ireland, and Eire. For overseas competitors the *mailing date* specified is 20 January 1962.